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CHARGE IDENTIFICATION FOR SPECTRAL LINES IN NITROGEN

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Abstract: A modified technique has been applied to the beam-foil light source to determine unambiguously and correctly the charge of the ions from which spectral lines are emitted. After transmission through the thin exciter foil, the luminous beam of ions passes through a transverse electric field of up to 70 kV/cm. The field introduces a Doppler shift which depends in magnitude on the charge state of the emitting ion and in sign on the direction of the field. In the spectral range of 3300 Å to 6000 Å, lines in nitrogen were distinguished and assigned to various transition arrays.

1. Introduction

One generally unfortunate feature of every light source which generates light from ionized emitters is that more than one stage of ionization is present. Consequently one must determine to which ion a given spectral line should be assigned. Traditional spectroscopy has relied primarily on three methods of achieving this identification - extrapolation of a distinct pattern of spectral lines along an isoelectronic sequence down to the neutral member (Edlén, 1964), intensity measurements as a function of the voltage

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applied in a spark discharge (Dieke et al. 1961, Bockasten et al. 1963), or theoretical calculation (Edlén, 1964) of the level system which could give rise to the observed spectra.

The foregoing methods, which have produced a wealth of unimpeachable identifications, are difficult to apply. Moreover, those methods cannot be said to be prima facie certain to lead to correct results. It is, therefore, of interest that the beam-foil light source (Bashkin, 1968) makes possible two additional techniques, one of which, like the traditional ones, is suggestive of the appropriate ionization stage, and one of which is rigorously correct.

The first of these techniques is to study the intensity of a spectral line as a function of particle energy (Kay 1965, Denis et al. 1969); some of the objections to this procedure have been discussed previously (Bashkin and Malmberg 1966). The second technique is to send the luminous beam through an applied electric (or magnetic) field so as to produce a separation of the particle paths according to the particle charge. Spectroscopic studies of the light from the separate paths can give a certain identification of the stage of ionization with which the spectra lines are associated.

Several authors have described experiments of the charge-splitting type. The first such paper (Malberg et al. 1965), in which observations were made normal to the plane of the split beam, depended directly on the spatial distribution of the trajectories of the ions of different charge. The second (Fink 1968) employed the suggestion (Träschlin 1968) that one take advantage of the differential Doppler shifts acquired by spectral lines when their parent ions are deflected in a transverse electric field; in that experiment, observations were made in the plane of the split beams. Other suggestions for charge-splitting experiments have also been advanced (Fink 1968).

The cited experiments used photographic plates as the ultimate photon detectors. There are various reasons - linearity of response vs intensity, direct-reading output, application in the vacuum ultraviolet - why photomultiplier detectors are to be preferred. In the present paper, we describe the use of photoelectric detection in charge-splitting research of the second type.

2. Experiment

A horizontal beam of N^+ ions, with an energy of 850 keV and an intensity of $\sim$ 0.7 μamp, was sent through a carbon foil, the thickness of which was estimated to be 6 $\mu gm/cm^2$. The pressure in the target chamber was $\sim 3 \times 10^{-6}$ Torr. After passage through the foil, the beam was collimated by a 2 mm, circular aperture in a thin grounded plate; it then entered the 5 mm gap between two vertical, parallel, metal plates. The plates had 3 mm-high slots centered at the elevation of the beam. A deflecting electrostatic field of up to 80 kV/cm, which could be reversed in sign, gave the ions a transverse velocity component which varied linearly with the ionic charge and the distance travelled in the field. Consequently the emitted spectral lines, when observed in the horizontal plane, were Doppler-shifted either to the red or the blue, depending on the sign of the field. The magnitude of the shift was a simple function of the wavelength, as measured in the rest system of the emitter, and the transverse velocity at the point of observation.

Although the Doppler shift is enhanced by looking as far downstream as possible, practical limitations are imposed by the finite mean lives of the radiating levels. Thus, intensity considerations militate in favour of early observation, and a compromise is demanded by the conflicting requirements of signal-to-background (enhanced by working near the foil) and spectral resolving power (which, aside from the matter of line blending, can be reduced by increasing the distance to the point of observation). In some cases, increasing the distance from the foil at which the data were taken reduced the contributions from short-lived levels and simplified the spectrum. Again, intensity problems limited how far one could go in this direction. The specific distances we used are indicated in fig. 1.

It is also apparent that the effects are strengthened by increasing the applied field. We were limited to 80 kV/cm because electrons, released at the foil, at the collimating aperture, and where positive ions struck various surfaces, caused excessive loading of the power supplies. They also triggered sparks at fields above

80 kV/cm. We might note that fields of this order introduce Stark perturbations of the energy levels (Bashkin and Carriveau 1970). Further remarks on this matter appear in the section on Discussion.

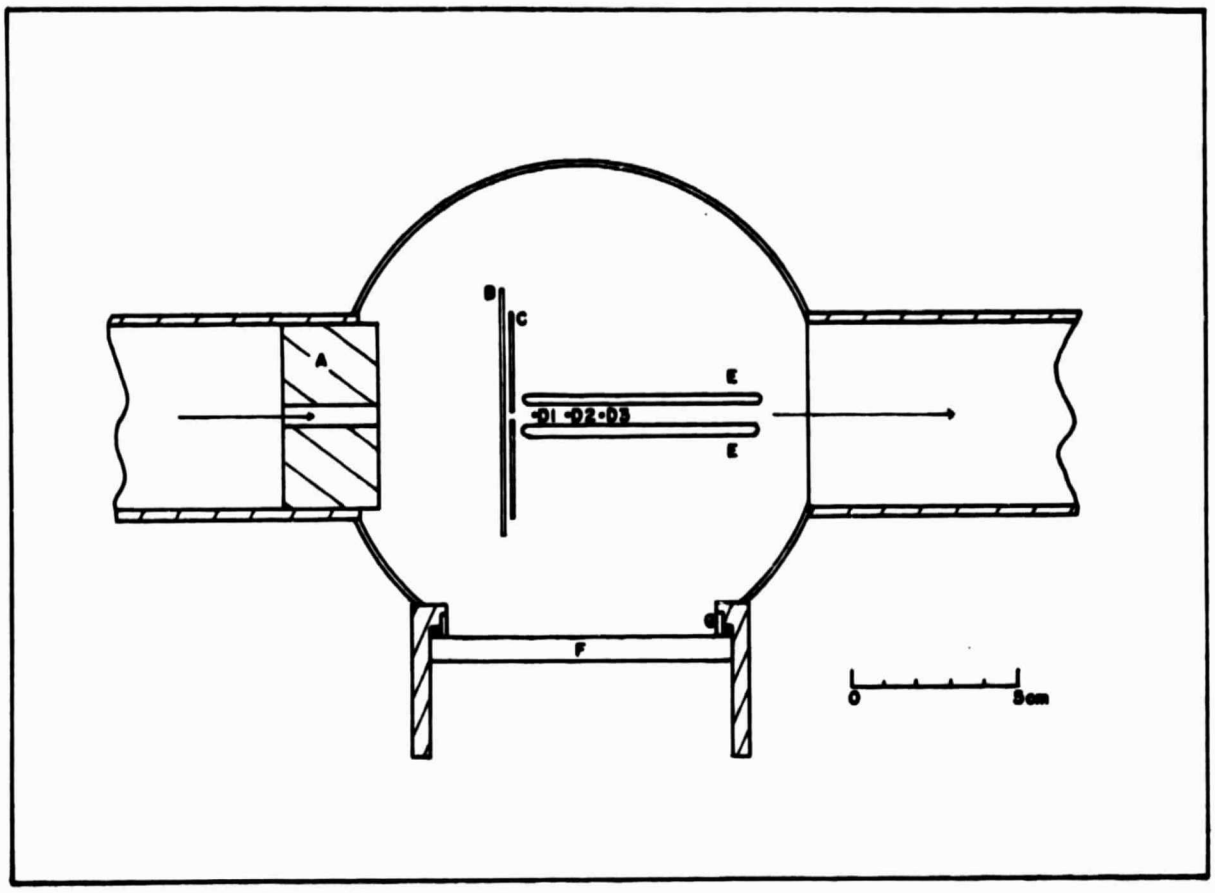

Fig. 1: Diagram of the beam-foil spectroscopy chamber. A. 6 mm pre-collimator. B. Foil-wheel holding 20 foils. C. Grounded collimator plate. D1, D2, D3. Points of observation 7 mm, 17 mm and 27 mm from foil. E. Deflecting plates, 5 mm separation. F. Glass window. G. O-ring seal.

As shown in fig. 2 observations were made through a glass window in the target chamber, the angle of observation being a nominal 90° to the particle velocity. A glass lens (focal length 10 cm) focussed and slightly de-magnified the light onto the 100-micron-wide entrance slit of the monochromator. The available monochromator, a Jarrell-Ash 1/4 metre, Ebert type, was fast (f/3.7) but gave an instrumental line width of ~ 6 Å. Because of this width many observed lines would not be properly resolved. The dispersed light which passed through the exit slit (width 100 microns) was detected with a selected 1P21 photo-multiplier which was radiatively cooled from a closely

fitting brass cylinder at the temperature of liquid nitrogen. To keep frost from condensing on the photomultiplier, a steady steam of dry nitrogen, released from a reservoir of liquid nitrogen and warmed to room temperature, blew over the photomultiplier and through the monochromator.

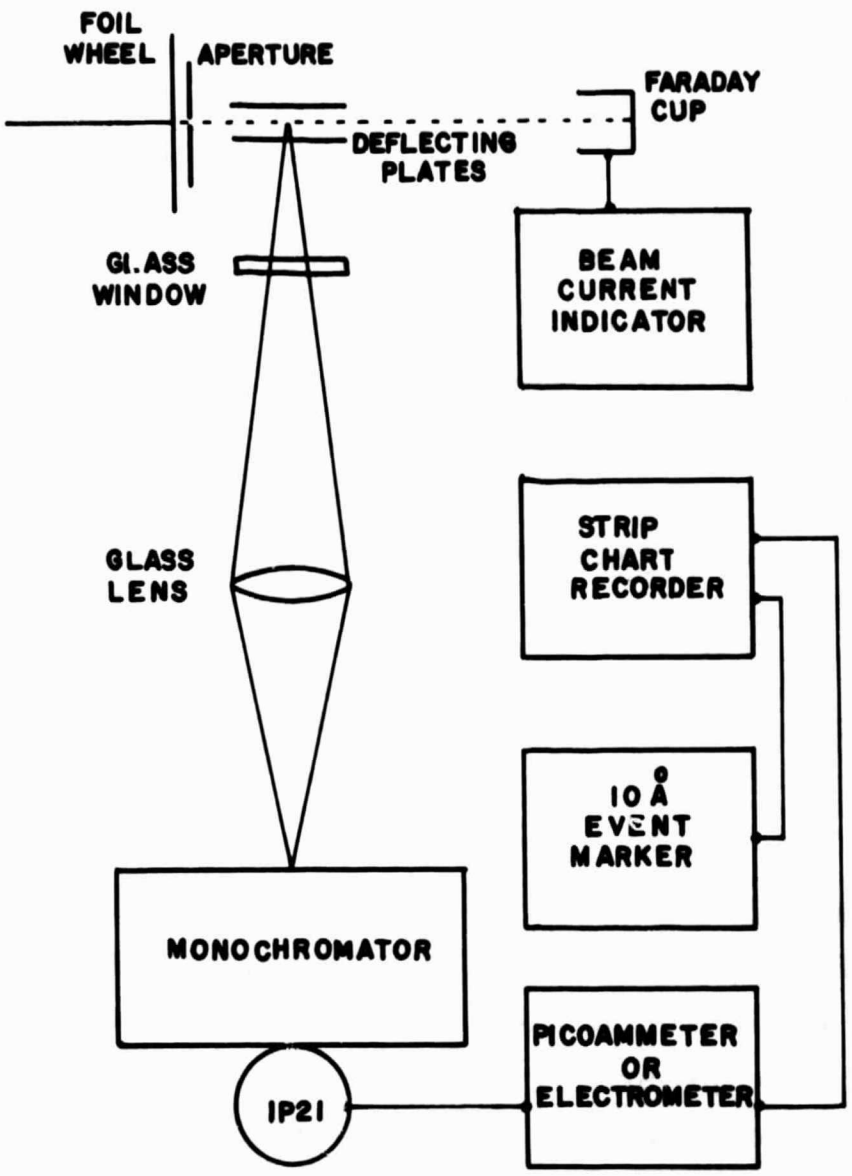

Fig. 2: Schematic of charge assignment apparatus.

The 1P21 was operated with -900 volts applied to the photocathode; the output of the photomultiplier was amplified with a General Radio Type 1230-A electrometer was used in its E-mode with an input resistance of 10^{10} ohm, or with a Keithley picoammeter. A permanent record was obtained with a strip chart recorder. The photomultiplier currents were usually of the order of 5×10^{-12} amp, but occasionally reached the level of 10^{-10} amp; thus weak signals were sometimes obscured by noise, and repetitive

runs were made to eliminate uncertainties. No beam monitor was used, and beam fluctuations were troublesome for very weak lines; however, many lines were seen without difficulty.

Since the basic data acquired in this experiment were on line intensity vs wavelength, wavelength calibration of the spectrograph was required. Standard lamps provided adequate calibration lines. As the grating was rotated by a synchronous motor geared to an appropriate speed, generally 50 Å/min, a marker pulse was manually triggered every 10 Å. The combination of instrumental line width, uncertainty in marker position, and other factors produced a final uncertainty of ± 2 Å in the wavelength of the centre of an isolated line; for other lines, the uncertainty could be twice as great. Neither the 90° Doppler shift nor the Doppler broadening which arises from the finite aperture of the viewing system was significant in the present experiment for the particle speed was low ($\beta = 1.14 \times 10^{-2}$ corresponding to a shift of 0.36 Å at 4000 Å) and the monochromator produced a large intrinsic line width.

3. Results

Figure 3b illustrates part of the spectral scan in the absence of any applied field; figs. 3a and 3c show the same spectral region when fields of +70 kV/cm and -50 kV/cm, respectively, were present. Table 1 lists in column 1 the wavelengths of the observed lines in the observed field and in column 2 the assignment permitted by wavelength alone. Column 3 gives the charge as determined from the present study.

4. Discussion

Three separate points merit mention. In the first place, it is clear that the method we used cannot distinguish between one level and another in the same ionization stage, when the spectral lines have the same wavelength. Thus the first entry on Table 1 could arise from either (or both) of two transitions in N III. Only better resolving power could help decide the relative contributions of such transitions.

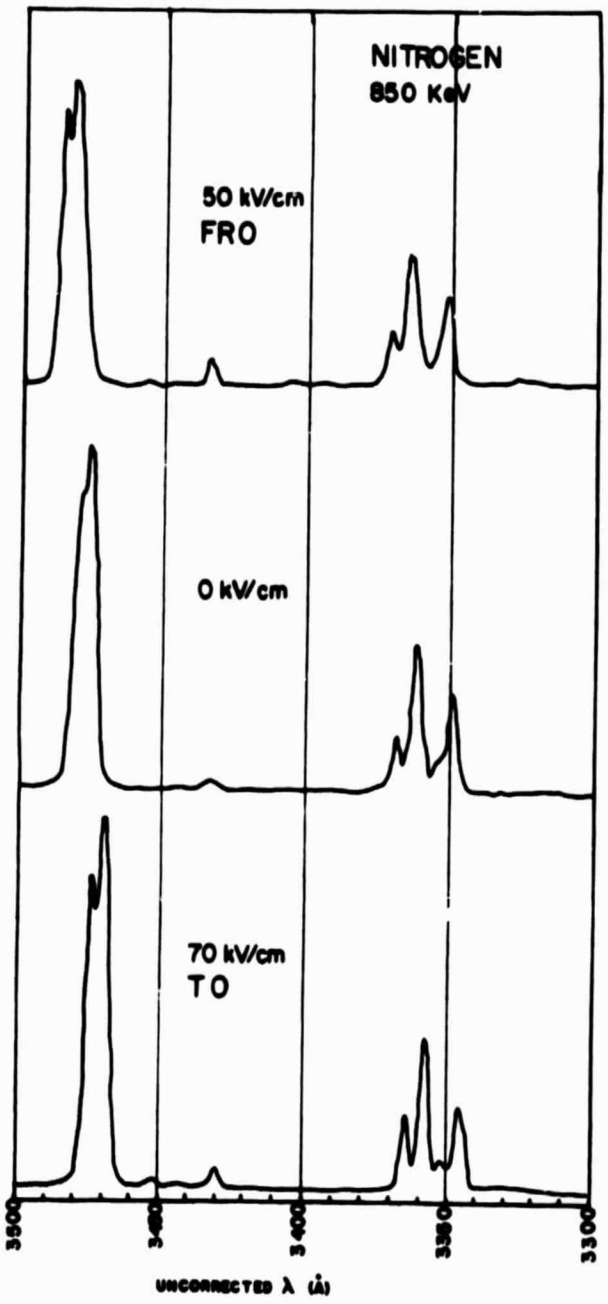

Fig. 3: Partial spectra showing Doppler-shift when:

a. +70 kV/cm deflecting field applied.

b. 0 deflecting field applied.

c. -50 kV/cm deflecting field applied.

Secondly, when blends from different charge states are possible within the wavelength uncertainty, as occurs for the entries marked with *, the field should clarify which charge states are actually present. Thus λ3748 is definitely broadened by the field. Although we could not detect two distinct lines we conclude from the broadening that there is a small contribution from N IV (8). In measurements at higher particle energy, any N IV (8) excited in the interaction would probably become stronger relative to the N III levels.

Thirdly, the Stark effect can produce some broadening and displacing of the spectral lines. However, the Stark effect is independent of the direction of the applied field so that it can, at least in principle, be

Table 1

Results of charge determinations.
Entries with * are discussed in the text.

Observed Wavelength (Å)	Identification from Moore (number) or Striganov and Sventitskii (+)	Present value of charge
3355	III (5,7)	2
3368	III (5)	2
3374	III (5)	2
3480	IV (1)	3
3484	IV (1)	3
3748*	III (4,11) IV (8)	2
3756	III (4,11)	2
3772	III (4,11)	2
3794	III (11)	2
3940*	II (+) III (8)	1
3957	II (6)	1
4026	II (40)	1
4042	II (39)	1
4097*	II (38) III (1)	2
4102*	I (10) III (1)	2
4133*	I (+) II (65)	1
4378*	II (16) III (17)	2
4535	III (3,13)	2
4605*	II (5) IV (+) V (1)	1,3,4
4620*	II (5) V(1)	1,4
4628*	I (+) II (5) III (2)	1
4641*	II (5) III (2)	1
5004	II (4,16,24,64)	1
5012	II (+)	1
5534*	I (+) II (63)	1
5679	II (3)	1

recognized and not confuse the charge state determinations. In the present case, the low resolution of the spectrograph and the instability of the beam made the record too uncertain for Stark effects to be identified reliably.

Returning to table 1, we consider the remaining entries which indicate the possibility of blends from

different charge states. At λ3940 Å there is no evidence for charge 2, although our other results (e.g. λ3748 discussed above) show that N III levels were populated in this experiment. We are forced to conclude that this line does not belong to N III, and that its identification with any of the N III, multiplet 8, lines in Moore's tables (Moore 1959) and Striganov and Sventitskii (1968) is incorrect. This agrees with similar work by Fink (1968) and Fink, McIntire and Bashkin (1968).

The pair of lines at λ4097, 4102 clearly belong to the same transition array in N III; there is no sign of blending with lines from N I or N II. Again at λ4378, the evidence favours N III, with no sign of N II.

At λ4605, the line is quite broad, and N II, N IV and N V are probably all present. Also, λ4620 clearly divides into two lines, corresponding to N II and N V constituents. At λ4628, only the N II line is present. Only N II is seen at λ4641. Finally, at λ5534, only N II is present.

In assessing the value of the present technique, there is the obvious advantage that isolated lines can definitely be given their correct origins. Moreover, the poor line shapes which are characteristic of beam-foil spectra do not preclude charge identification. Perhaps the most serious drawback is that line intensities vary with particle energy in a complicated, and presently unpredictable way. Thus, while it is correct to conclude that λ3940 is part of the N II spectrum, it is somewhat speculative to say that it is not present in the N III spectrum - it might be. Perhaps a different particle energy would give rise to such a line that would indeed originate in N III. There is even the possibility that another type of light source could generate an N III line which the beam-foil source could not. However, this is a handicap of the source and not the method we have used. The method does permit the charge classification of whatever spectral lines can be seen.

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